

A High Rate K_a -band Aeronautical Satellite System

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ABSTRACT

This paper will introduce a system to provide high rate aeronautical services at K_a -band. K_a -band is particularly attractive for aeronautical communications as weather effects become inconsequential. The system consists of 3 satellites with one ground spare, aircraft equipped with aeronautical mobile terminals, and ground stations interconnected to multiple public and private networks. A plethora of voice, data and real-time video services can be provided to passengers. An experimental version of this system will be trialed using the NASA ACTS satellite beginning in 1994.

INTRODUCTION

In the mid-80's, airlines introduced terrestrial-based communication services for the passenger cabin. This service was limited to a single channel (per aircraft) analog voice communication. The quality of this voice channel was rated as sub-toll at best (3 kHz

bandwidth). Several years later, with the technological advancement of L-band communication, mobile satellite communication (satcom) was introduced to the airline industry. Initially, this service was used for cockpit communication (1200 bps data communication), but as the industry grew, passenger cabin mobile satcom was born. In 1989, Inmarsat introduced single channel voice communication (4.8 kbps -- toll quality). Since then, Inmarsat has expanded this service to multiple channel voice (9.6 kbps per voice channel), and the American Mobile Satellite Consortium (AMSC) will be following suit with similar services within the next year. In late 1992, USA Today/CNN Sky Radio introduced a dual channel news and sporting events broadcast at Ku-band. As these passenger services continue to grow, and the currently allocated L- and Ku-band spectrum for mobile satellite services (MSS) becomes saturated, an alternative frequency band, and its accompanying system, will need to be developed.

A particularly attractive alternative to L- and Ku-bands is a K/K_a-band system. K/K_a-band aeronautical mobile satcom is extremely attractive for several reasons. The higher frequencies associated with K/K_a-band results in high-gain, low profile antennas. Such a low profile antenna is critical for minimizing aircraft drag. Second, the K/K_a-band spectrum is virtually untapped, with only minimal operational use by the Deep Space Network and the military. Many gigahertz of bandwidth is readily available for expanding mobile satcom services. Lastly, a major problem associated with K/K_a-band land-mobile satcom, environmental attenuation due to vegetation shadowing and rain events, is virtually eliminated for K/K_a-band aeronautical satcom.

EMERGING AERONAUTICAL SATELLITE SERVICES

Due to the vast amounts of available bandwidth, improved aeronautical mobile satcom services will be available with such a K/K_a-band system. The current systems with capacities on the order of several tens of kilohertz, could be replaced with new systems supporting at least ten times this capacity. With such a system, many new and exciting communication services would be available to passengers. One of the more exciting possibilities for a new service is compressed video broadcasting. With such a system, compressed video television broadcasts to an aircraft would be possible. Live CNN news broadcasts, prime time television programming, or even real-time coverage of the World Series and the Super Bowl in an aircraft cabin would become reality.

Other possibilities for these expanded services include establishing an "office-in-the-sky" for the ever working businessman. This setup would include such services as telephone, modem, FAX, and video teleconferencing. Other passenger amenities would be available such as re-ticketing of passenger's enroute, and

providing up-to-the-minute airport connecting gate information. For international flights, the possibility exists to conduct currency exchange transactions' enroute.

Current cockpit communication capabilities on transoceanic flights are limited to approximately 2.50 miles offshore (line-of-sight communication) with the exception of aircraft equipped with Inmarsat aeronautical services. While K/K_a-band mobile satcom will never be the primary cockpit communication method (due to the reliability deficiencies experienced at these frequencies), using this system during the cruise phase of flight (during which K/K_a-band mobile satcom is more reliable) would improve the overall safety conditions on these flights.

SYSTEM CONFIGURATION

The basic system configuration is shown in Figure 1. Full-duplex communication would be possible between an aeronautic mobile terminal and a fixed terminal via a K/K_a-band satellite. The fixed terminal would provide broadcast capabilities and direct connections into a variety of terrestrial networks.

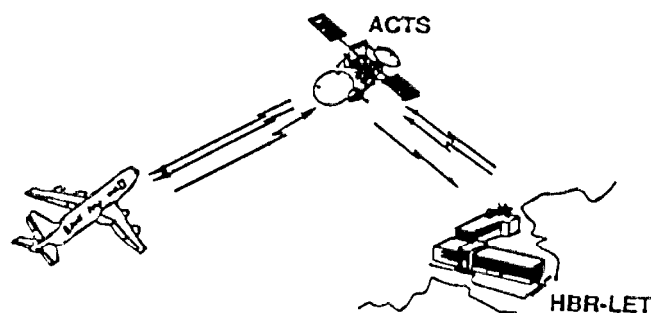


Figure 1: Baseline System Configuration

This system would be able to provide two channels of compressed video broadcast (simplex link -- 1,544 kbps) from the fixed terminal to the aeronautical mobile terminal. The fixed terminal would also be able to provide up to 87,500 additional narrowband channels for voice, data, fax, etc. Each

aeronautical mobile terminal would be able to receive and transmit up to 35 channels for similar purposes.

The system consists of three major components as shown in Figure 2: the space segment which is composed of three or more satellites, the aeronautical mobile terminals inside the commercial aircraft, and the ground segment. The ground segment consists of the Gateway Stations or fixed terminals, and the operational facilities including the Network Control Center (NCC), the Satellite Control Center (SCC), the maintenance center, and the Tracking, Telemetry, and Control (TT&C) Stations.

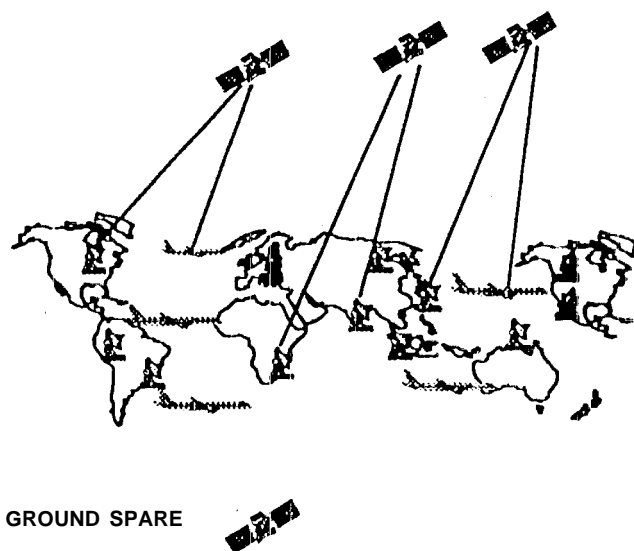


Figure 2: The Aeronautical Mobile Communication System

Space Segment

The system assumes a three satellite configuration for complete global coverage. The first satellite would be located over the Atlantic Ocean (40° W) for coverage of eastern North and South America, trans-Atlantic, and western Europe. For coverage of western North America, trans-Pacific, and eastern Asia, a second satellite would be located over the western Pacific Ocean (160° W). The third satellite would be located over the western

Indian Ocean (80° E) for coverage of Eastern Europe and the Middle East. Geosynchronous altitude was also assumed which effectively rules out coverage of the North and South Pole regions. Inclined orbits at lower altitude may bring the benefits of complete earth coverage and smaller path loss at the cost of requiring more satellites and increased system complexity.

The satellite antenna and beam forming network generate 5000.78° spot-beams to illuminate the entire field of view of the earth from the satellite. The satellite antenna gain at the edge of coverage is 43.5 dBi. The EIRP for each spot-beam varies with the instantaneous number of aircraft in each beam. The average (over all spot-beams) value of the EIRP at the edge of the spot-beam is 46.6 dBW. This value will increase to 53.1 dBW if a large number (50) of aircraft happen to be in the same spot-beam. Each spot-beam will cover an area of 0.115 million square miles (0.3 million sq. km), Figure 3 shows the footprints of 7 spot-beams covering parts of North America. For simplicity in the initial operation, the communications payload will employ a bent-pipe transponder design enabling a duplex phone connection between an aircraft mobile terminal and a gateway/fixed terminal which can then interconnect with one or more terminals on the ground via the appropriate terrestrial networks. As the system matures, an on-board baseband processor could replace the bent-pipe transponder for the provision of a variety of service offerings including mobile to mobile communications.

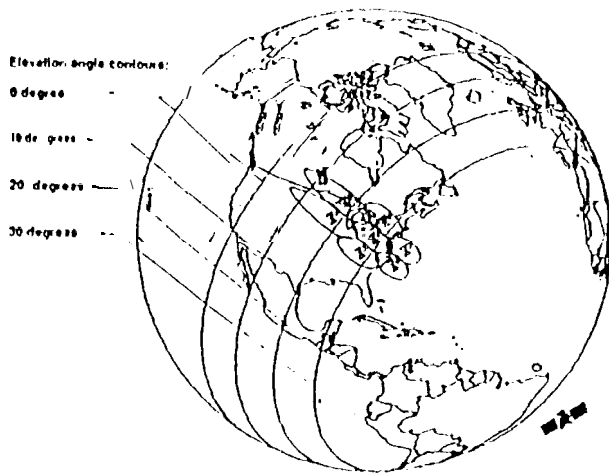


Figure 3: Coverage of North America and North Atlantic by a GEO Satellite at 40° West (showing footprints of seven 0.78° spot-beam)

The Aeronautical Terminal

Figure 4 shows the main elements of the Aeronautical Terminal, namely the antenna and front end mounted outside the fuselage, the transceiver and processors inside the cabin, and the user terminals.

The on-board user terminals dedicated to each passenger seat include telephone handsets and computer ports. Common user equipment includes several TV projectors mounted overhead, TV monitors for viewing, and a mobile office offering fax, video teleconferencing and other services.

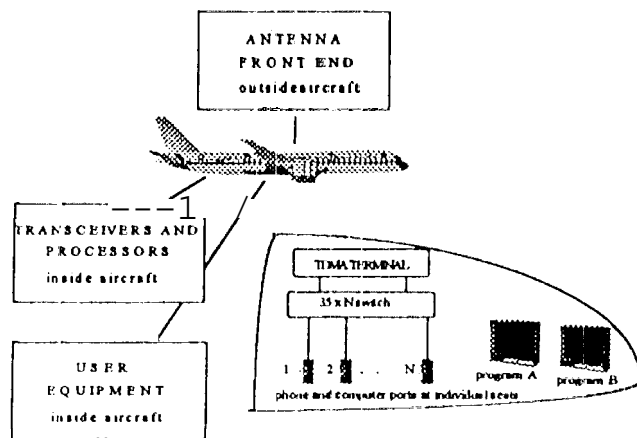


Figure 4: Aircraft Equipment

The Ground Segment

Figure 5 shows the main features of the ground segment, namely the Satellite and Network Control Stations (one per satellite), and the Gateway Earth Stations (six per satellite). Each Gateway Earth Station provides access to a variety of public and private networks. The Gateway Stations should be deployed in areas in locations where heavy rainfall is rare to avoid excessive rain attenuation. Placement of the Gateway Stations in regions of low rainfall will also allow the reuse of the spectrum between the satellite-aircraft links (horizontally polarized) and the satellite-gateway links (vertically polarized).

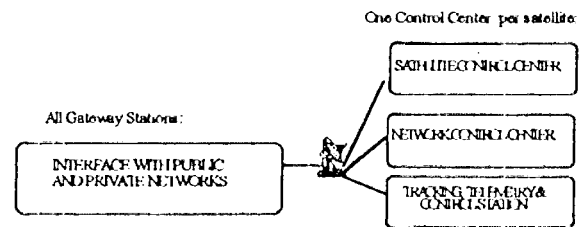


Figure 5: Ground Segment

Frequency Spectrum Utilization

Figure 6 shows a typical spectrum utilization plan for the High Rate Aeronautical Satellite System based on the availability of 320 MHz of spectrum at around 20 GHz for downlinks from the satellite to both the fleet of aircraft and the Gateway Stations. A corresponding 320 MHz of spectrum around 30 GHz is assumed for the uplink from both the fleet and the Gateway Stations to the satellite.

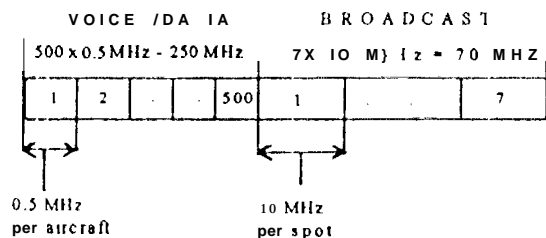


Figure 6: System Spectrum Allocation

The use of two separate polarizations (vertical for transmissions to and from the ground stations, and horizontal for transmissions to and from the fleet) allows the same spectrum to be reused by both the Gateway Stations and the aircraft fleet. Furthermore, due to their geographical separations, the six Gateway Stations can reuse the same spectrum. Since coverage of aircraft fleet is through spot-beams, the same spectrum can be reused by non-adjacent spot-beams (every seven) for transmissions to and from the aircraft.

For this system, 250 MHz of spectrum at each of the bands (20 & 30 GHz) is dedicated for duplex communication between the aircraft and the Gateway Stations with the satellite acting as a repeater. This 250 MHz spectrum pair is frequency divided into 500 0.5-MHz duplex channels. Each duplex channel can support 35 4.8 kbps voice or data channels in a TDMA mode. One can assume that one TDMA channel (35 4.8 kbps voice/data channels) will have more than enough capacity to serve a single, large aircraft.

To provide high quality compressed digital video broadcasts to the air fleet, two T1 broadcast channels have been envisioned as shown in Figure 7. It is assumed that the two T1 channels can be conservatively accommodated in 10 MHz after ample allowance for FEC (rate 1/3) to keep the bit error rate around 10^{-6} or better, required for high quality compressed digital video. To avoid interference between adjacent beams, 70 MHz of spectrum is required to broadcast the two channels of video over each of the seven adjacent spot-beams. Non-adjacent beams can use the same spectrum.

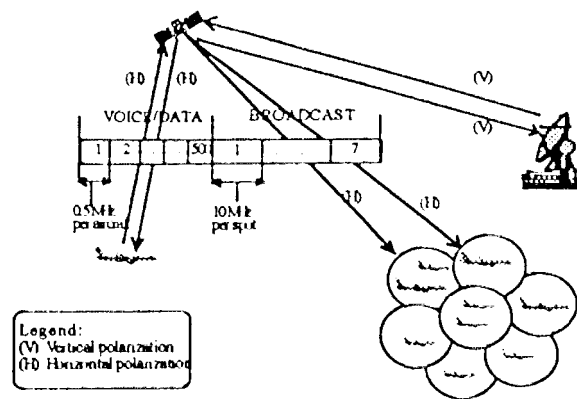


Figure 7: Spectrum Utilization Plan

SYSTEM OPERATIONS

Each satellite operates as a central node in a star network, in which the aeronautical mobile terminal will communicate via the satellite with one of the terrestrial-based gateways to allow interconnect with terrestrial public and private networks. These networks include the PSTN, airline networks, video distribution networks, as well as many others.

The satellite acting as a repeater provides 1000 TDMA trunks each providing 35 duplex 4.8 kbps voice or data lines between each aircraft and the Gateway Station. With this ample capacity per aircraft, both the telephony and the data communications needs of passengers can be served.

Two high quality compressed digital video programs are broadcast to the aircraft fleet via the two one-way (forward) T1 channels to each of 7 adjacent spot beams. This is shown in Figure 7.

FUTURE PLANS

The next steps in realizing a high rate aeronautical satellite systems involves testing out system concepts through experimentation. NASA's ACTS (Advanced Communications Technology Satellite) is scheduled to be launched this July and will provide such an

for new services such as real-time video broadcasts, office-in-the-sky scenarios, and enroute re-ticketing of passengers. K_a-band is particularly well suited for aeronautical applications as weather events are mitigated. The envisioned system consists of three satellites (and a ground spare), aircraft equipped with aeronautical mobile terminals and ground stations interconnected with multiple public and private networks. As a first step towards realizing such a system, the NASA ACTS satellite will be used to run experiments designed to test the feasibility of the configurations detailed above. These experiments will begin in 1995. It is expected that these experiments be intermediate steps to realizing the envisioned system.

A. (ACKNOWLEDGMENTS

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